Aqua: An Earth-Observing Satellite Mission to Examine Water and Other Climate Variables

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***Abstract*—Aqua is a major satellite mission of the Earth Observing System (EOS), an international program centered at the U.S. National Aeronautics and Space Administration (NASA). The Aqua satellite carries six distinct earth-observing instruments to measure numerous aspects of earth's atmosphere, land, oceans, biosphere, and cryosphere, with a concentration on water in the earth system. Launched on May 4, 2002, the satellite is in a sun-synchronous orbit at an altitude of 705 km, with a track that takes it north across the equator at 1:30 P.M. and south across the equator at 1:30 A.M. All of its earth-observing instruments are operating, and all have the ability to obtain global measurements within two days. The Aqua data will be archived and available to the research community through four Distributed Active Archive Centers (DAACs).**

***Index Terms*—Aqua, Earth Observing System (EOS), remote sensing, satellites, water cycle.**

I. Introduction

LAUNCHED IN THE early morning hours of May 4, 2002, Aqua is a major satellite mission of the Earth Observing System (EOS), an international program for satellite observations of earth, centered at the National Aeronautics and Space Administration (NASA) [1], [2]. Aqua is the second of the large satellite observatories of the EOS program, essentially a sister satellite to Terra [3], the first of the large EOS observatories, launched in December 1999. Following the phraseology of Y. Kaufman, Terra Project Scientist at the time of the Terra launch, the Terra and Aqua satellites are aimed at monitoring the "health of the planet," with Terra emphasizing land and Aqua emphasizing water. Both satellites, however, measure many variables in the atmosphere, on the land, and in and on the oceans. In fact, two of the key EOS instruments are on both the Terra and Aqua platforms.

Aqua data are providing information on water in its many forms: water vapor in the atmosphere; liquid water in the atmosphere in the form of rainfall and water droplets in clouds; solid water in the atmosphere in the form of ice particles in clouds; liquid water on land in the form of soil moisture; solid water on land in the form of snow cover and glacial ice; liquid water in the surface layer of the oceans; and solid water in the oceans in the form of sea ice floating in the north and south polar seas. Aqua data are also providing information on land and ocean vegetation, heavily dependent on water, and on many other aspects of the earth's climate system. A particular highlight, in addition to the data on the water cycle, are improved atmospheric temperature data, which, along with the humidity measurements, have the potential of leading to improved weather forecasts.

Fig. 1. Aqua spacecraft, August 2001, at TRW, Redondo Beach, CA. TRW was the prime contractor for the Aqua spacecraft bus. The two CERES instruments are visible near the bottom of the spacecraft, both with protective covers. The HSB is immediately above the rightmost CERES, and the AIRS is to its left. Above the HSB is one of the two major units of the AMSU (AMSU-A2), and above the AIRS is the other (the AMSU-A1). MODIS is at the top left, and AMSR-E is at the top right (photo by S. Aristei/TRW).

Aqua carries on board six distinct earth-observing instruments: the Atmospheric Infrared Sounder (AIRS), the Advanced Microwave Sounding Unit (AMSU), the Humidity Sounder for Brazil (HSB), which was provided by the Brazilian National Institute for Space Research, the Advanced Microwave Scanning Radiometer for EOS (AMSR-E), which was provided by Japan's National Space Development Agency, the Moderate Resolution Imaging Spectroradiometer (MODIS), and Clouds and the Earth's Radiant Energy System (CERES) (see Fig. 1). The data from these instruments are being used to examine

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dozens of earth system variables and their interactions. The multiple goals of the mission include enhanced understanding of the global water cycle, enhanced understanding of many additional elements of earth's climate system, enhanced understanding of climate interactions and climate change, enhanced understanding of the diurnal cycle of variables measured by both Aqua and Terra, and improved weather forecasting. The mission is planned to last on orbit for six years.

3) New Spaceborne Observations

Most of the Aqua data products are products that have been generated previously from other spacecraft (although perhaps from different algorithms and at different resolutions or accuracies). For instance, the MODIS and CERES products have almost all been generated previously from the Terra MODIS and CERES data; most of the AMSR-E products have been generated previously from SMMR and/or SSM/I data; and many of the AIRS/AMSU/HSB products have been generated previously from NOAA data. Still, there are some important new products (or new aspects), among them being a land evaporation fraction from MODIS data, nighttime ozone measurements from AIRS/AMSU/HSB data, and validated global soil moisture from AMSR-E data.

The MODIS land evaporation fraction is the energy budget equivalent of the ratio of actual to potential evapotranspiration and is calculated by a method based on normalizing the radiometric surface temperature with NDVI values [55]. Potential applications include water resources management and analysis of vegetation stress and wildlife fire risk. The evaporation fraction is not being derived routinely from the Terra MODIS data, as it is expected to be from the Aqua MODIS data, but it has been tested on the Terra data in preparation for Aqua [55]. The advantages of Aqua over Terra for this product include the early-afternoon timing (for much of the globe) of the Aqua daytime passes [63] and the synergistic value of having AIRS, AMSU, HSB, and AMSR-E flying along with MODIS on Aqua. Regarding the latter, of particular importance are the temperature and water vapor profiles provided by AIRS/AMSU/HSB and the soil moisture information provided by AMSR-E [55].

The AIRS/AMSU/HSB ozone measurements have an advantage over previous satellite-derived ozone measurements in not requiring solar radiation and therefore allowing a nighttime as well as a daytime product. The Total Ozone Mapping Spectrometer (TOMS) has provided a strong record of satellite-derived ozone measurements since late 1978 [56], and the TOMS data will serve as a primary standard against which to validate the AIRS/AMSU/HSB ozone product under daylight conditions. However, the TOMS measures ultraviolet radiation and therefore requires sunlight. This is restrictive for examining polar phenomena, such as the Antarctic ozone hole, because of the absence of sunlight in the high polar latitudes for months at a time [57]. The AIRS/AMSU/HSB data are obtainable for all latitudes throughout the year and thus offer the exciting possibility of space-based observations of the Antarctic ozone hole in the midst of the Antarctic winter, supplementing the current TOMS observations for the rest of the year.

Another atmospheric trace gas that might be derived from the AIRS/AMSU/HSB data is carbon dioxide (CO_2). CO_2 is not a standard product for the Aqua mission but is a research effort within the AIRS/AMSU/HSB Science Team. If successful, this effort could lead to the first satellite-derived global monitoring of the second most important greenhouse gas in earth's environment, exceeded in importance only by water vapor.

AMSR-E is expected to provide the first routinely produced and scientifically validated spaceborne measurements of global soil moisture [61], advancing on earlier, more limited studies using data from SMMR, SSM/I, and TMI (e.g., [58] and [59]). Soil moisture is a key determinant of surface evaporation, runoff, and water availability for agriculture and other human uses, and is a key for improved hydrologic modeling, weather and climate prediction, and flood and drought monitoring [42]. None of the Aqua instruments is ideal for measuring soil moisture, but the AMSR-E provides a start. Satellite-based soil moisture measurements would most likely be better from instruments measuring at frequencies of about 1–2 GHz (L-band), although somewhat higher frequencies, as in the lower frequency channels of AMSR-E, are also useable [42]. Low frequencies are desired to limit contamination by vegetation cover and atmospheric effects. Only the Nimbus 7 SMMR, operational from late 1978 through mid-1987, has so far provided long-term global data at a frequency below 10 GHz (6.6 GHz specifically). However, because of the difficulties of obtaining soil moisture and the coarse spatial resolution (140 km) of the SMMR 6.6-GHz data, there was no dedicated algorithm development program for deriving soil moisture from the SMMR data. With AMSR-E, a soil moisture product is being calculated from the 6.9-, 10.7-, and, to a lesser extent, 18.7-GHz channels, at approximately 60-km spatial resolution [42]. The derived values are representative of only about the top 1 cm of the soil layer and are valid only under conditions of little or no vegetation. However, low vegetation areas are often precisely those where issues of water availability are most crucial. Thus, despite the limitations (which also include 6.9-GHz radio frequency interference in some regions, as discussed in [42]), the AMSR-E soil moisture measurements are an exciting new possibility, and they should serve as an important step toward future dedicated soil moisture missions measuring at lower microwave frequencies [60]. The dedicated missions will obtain soil moisture representative of a deeper layer of the soil (a few centimeters) and valid over a wider range of land conditions than the AMSR-E product [60].

The 6.9- and 10.7-GHz channels on AMSR-E (not available on SSM/I) are also being used to calculate sea ice temperature [41] and sea surface temperature (SST) (Fig. 3). SSTs are currently being calculated from TMI data for the tropics, but the AMSR-E allows all-weather SST measurements to be obtainable at higher latitudes as well, not restricted to the 40°S–40°N geographic coverage of TRMM.